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Photographic Assessment of Dark Spots in Night Vision Device Images

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ABSTRACT
Visible defects in night vision device (NVD) images, arising from image intensifier (I^2) tube defects and dirt on the device's optics, can become more than cosmetic blemishes. They can act as visual distractions and may be large enough to mask critical information pilots need to conduct normal night vision operations. This paper is concerned with the assessment of NVD dark spots. Current methods of assessing dark spots examine only the image intensifier tube, ignoring spots due to dirt and dust introduced during night vision device assembly. Current methods are limited in the size of spot that can be counted and do not address the issue of spot contrast. This paper discusses a photographic method for classifying, locating, and counting dark spots in an assembled night vision device.

Also documented in this paper is an experiment to determine an observer's ability to classify round dark spots, conducted as part of an effort to determine the accuracy of the photographic test procedure. To quantify the defects, they were classified by size and then counted. Inspectors used a comparison key as an aid in categorizing dots by size. The defect specification should not exceed the classifiers' visual discrimination capabilities. This study directly examined the dot size classification performance of observers using dots of 3, 4, and 6 minutes of arc (MOA) in diameter.

INTRODUCTION

A dark spot is anything appearing dark to an observer viewing the output of an I^2 tube with the input illuminated by a uniform light. Dark spot defects can be caused by photocathode burns, broken or contaminated (blocked) fibers in the fiber optic twister, bad channels in the microchannel plate, phosphor burns, or dust on the outside surfaces of the I^2 tube. These defects manifest themselves as black spots of varying sizes and can be located anywhere in the field of view. Centrally located black spots may have a greater deleterious affect on the observer's visual performance than do those located in the periphery due to the importance of foveal vision [Ronchi, 1957].

Not all blemishes appear perfectly black. An obstruction inside the I^2 tube's fiber optic twister might appear gray but could still obscure valuable visual information, especially in dim light. For the purposes of these tests, a minimum contrast, C (as defined by Equation 1), of 30 percent was adopted. Blemishes exceeding a contrast of 30 percent were counted as a dark spot [MIL-I-49428(CR)]. In Equation 1, L_1 and L_2 are the luminance of the bright background and the luminance of the dark spot respectively.

$$C = \frac{L_1 - L_2}{L_1 + L_2} \qquad (1)$$

For years, pilots and aircrew members experienced in NVD operations have known that dark spots in the NVD field of view were distracting. In response, as part of a program to develop an ejection compatible NVD for the U.S. Air Force, an effort was started to improve NVD image quality by significantly reducing the number and size of blemishes, or dark spots, in the NVD field of view. Available dark spot specifications, such as those for the Army's Aviator's Night Vision Imaging System (ANVIS) and the Navy's Cat's Eyes NVD were considered too loose. Older specifications called for 10.3 MOA spots as the smallest to be graded [MIL-I-49428(CR)]. New requirements necessitated the measurement of spots as small as 3 MOA [F33657-91-R-0045].

Classifying and counting dark spots of this size is difficult using current methods. The diameters of countable spots were considerably smaller than previously required for any NVD. Initial efforts at spot measurements used a ten-power (10X) microscope to directly view the image intensifier tube output [MIL-I-49428(CR)]. The magnification was low enough to allow an observer to view the entire tube output all at once and made for quick tube examinations. Unfortunately, it was difficult to use this method to quantify the small blemishes countable under the new dark spot requirement nor could it account for dark spots due to dirt introduced during NVD assembly. Increasing the microscope magnification improved the sensitivity of the procedure, but this approach was limited by the luminance output of the I^2 tube. Also, the observer could no longer view the entire tube output, significantly slowing the process and reducing their ability to accurately catalogue a spot's location.

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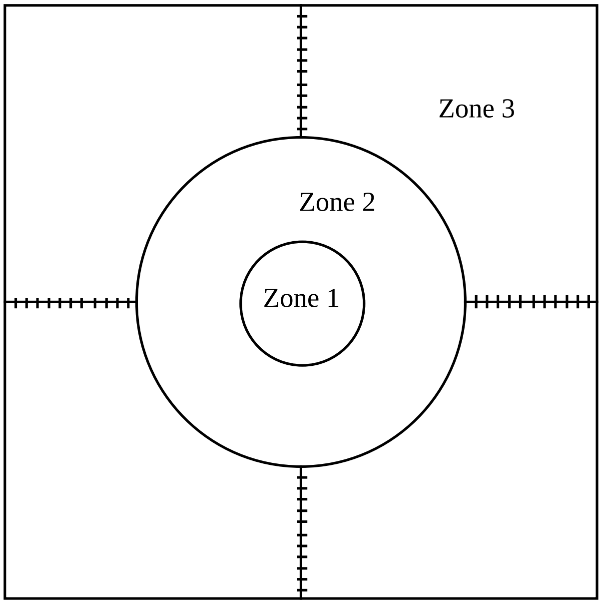

Figure 1. Current dark spot target design.

To overcome the disadvantages of current dark spot tests, a new procedure was developed, involving photographing the NVD output under lighting controlled to yield the best photographs. Then, a trained observer would examine the photographs to catalogue the size and zone of tube blemishes.

Dark Spot Photography

This experiment was conducted in a room with light control capable of complete darkness. Before attempting the assembly and positioning of the required equipment, the eyepiece lenses of the NVD and the data acquisition camera were focused to optical infinity. The camera lens was also set to infinity by focusing on a sufficiently distant object.

With the room lights on, the Dark Spot Target (see Figure 1) was positioned against a wall, perpendicular to the optical axis of the NVD under test. The minimum target dimensions were calculated using trigonometry and based on testing a 40-degree field-of-view NVD at a testing distance of 5 feet (60 inches) from the NVD objective lens. Zone diameters were also calculated using trigonometry. Zone 1 was a 5 degree radius circle centered in the NVD field of view. Zone 2 was an annulus having an inner radius of 5 degrees and an outer radius of 13 degrees. Zone 3 encompassed everything outside of the 13 degree radius circle. The target was plotted on white paper with lines one eighth of an inch thick, subtending about 7 MOA (Figure 1) and mounted to white foam-core board. Small marks were added to horizontal and vertical lines through the outer zone at 1 degree intervals, to aid NVD alignment.

The test NVD was then positioned using its helmet mount and other optomechanical parts on a tripod such that the test ocular was five feet from the target and roughly centered on the target at the same height as the target center. A Nikon 35 mm single lens reflex camera with a 28 mm focal length wide-field-of-view Nikon lens was then mounted to another tripod and placed in position behind the test NVD.

Next, a lamp was fitted with a 7.5 Watt frosted incandescent light bulb and attached to an aluminum rail, which was bolted to a photographic tripod. A mask was placed over the lamp housing to reduce the lamp to a 31 mm diameter source. An 8 X 10 inch, one quarter inch thick Plexiglas piece was fixed to the end of the rail, perpendicular to a line from the lamp to the center of the target. Light shaping filters were held by their edges to the Plexiglas sheet with cellophane tape. Then, the distance between the lamp and the filter was adjusted to closely match the filter's design distance. The lamp and filter were positioned slightly behind, above and off to one side of the camera such that the camera did not cast a shadow into the test NVD's field of view.

Light Shaping Filter

Several characteristics of the NVD output make photography difficult. The I^2 tube itself inherently has a three to one center to edge luminance falloff (see Figure 2) making the center of the NVD image much brighter than the edge. This effect is not very noticeable to an observer due to the human eye's logarithmic luminance response [Cornsweet, 1970]. However, it is much easier to capture this luminance falloff on film. This undesirable phenomenon can mask the desired information printed on a photograph.

Another phenomenon that hinders NVD photography is the illumination of the target. Theoretically, if a Lambertian extended light source is used to illuminate the entire target, a "Cosine-to-the-Fourth" luminance falloff would be seen on the target [Dereniak, 1984]. This is noticeable because of the size of target required to fill the entire NVD field of view.

To overcome the effects of these phenomena, a filter exhibiting non-uniform absorption was used to alter the illumination falling on the target. To design the lamp filter, the two falloffs were normalized and multiplied together as a function of angle, labeled "Total Falloff" in Figure 2. Filter transmissivity would have to have the inverse profile with large attenuation in the center and gradually decreasing towards the edges of the target, as shown in Figure 3. The scale in Figure 3 was normalized based on the light passed through the center equaling unity. Filters were generated using a computer drawing package and printed onto overhead transparency material using a laser printer.

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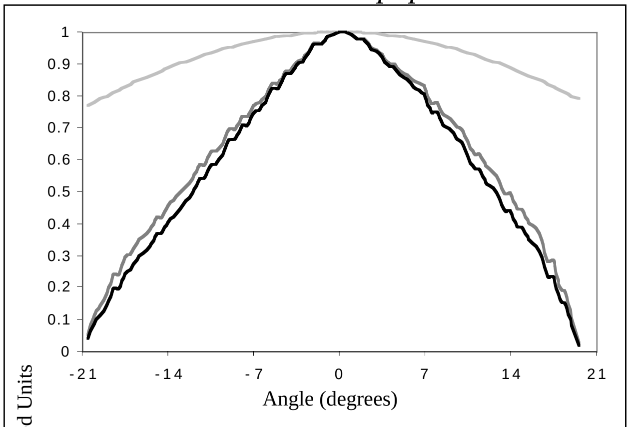

Figure 2. NVD luminance falloff.

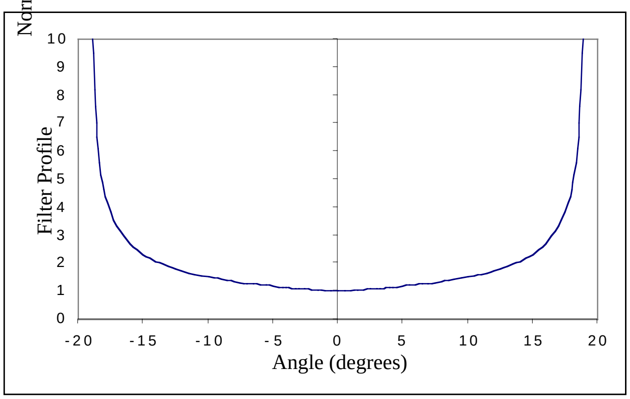

Figure 3. Theoretical lamp filter profile.

The next step was to illuminate the target with the non-uniform light source. After alignment of the NVD and camera, the luminance profile on the target was measured using a low light photometer. Overall luminance could be adjusted by changing the distance separating the lamp and the filter. Normally, data photos were taken with a target luminance profile of approximately full moon (2.0X10-2 foot-Lamberts(fL)) in the center and approximately three times full moon (6.5X10-2 fL) near the edge of the field of view. While this was not the profile required for perfectly uniform photographs, it did, however, prove adequate.

Fine alignment began with the room lights turned off and the filtered lamp turned on, illuminating the target. The NVD was turned on and focused on the target using the NVD objective lens. Next, the target was centered in the field of view by adjusting the height and tilt of the NVD/camera combination. Final alignment and centering were performed by counting the hash marks between the Zone 2 circle and the edge of the NVD field of view. The NVD and camera were centered on the target when an equal number of marks were counted to left and right, above and below the Zone 2 circle.

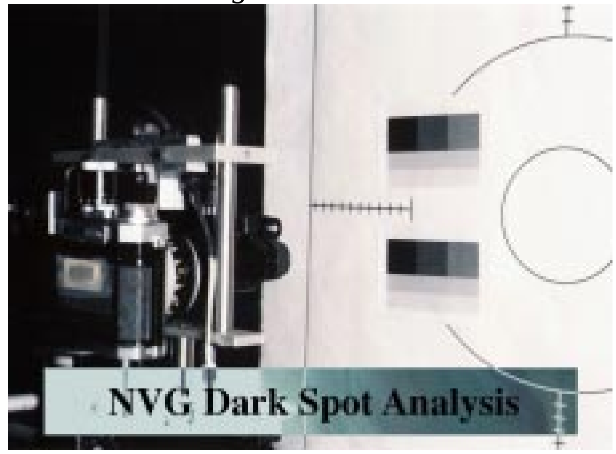

Figure 4. Equipment setup.

Photography and Processing

The film used was Kodak Technical Pan 2415, black and white, fine-grain with an ASA of 25. It was well suited for NVD dark spot photography because it was capable of very high-resolution photographs due to its fine grain size. The photos were then taken using a series of exposure times ranging from 0.25 to 8 seconds at f/5.6. Exposure times of one or two seconds yielded the best data. Computer generated contrast templates (see Figure 4) were then placed on the wall target in four places and photographed at the same f-number and exposure times as the dark spot data. These contrast reference photos were used later to determine if a spot in a data photo can be counted, exceeding the 30 percent contrast limit, or ignored. The film developing procedure required 1 to 1.5 minutes in Dektol developer, 4 minutes in fixer solution, and then rinsed for 8 minutes.

Data photographs were then enlarged and printed using a common printing process. To review the data, full 8 X 10 inch prints were made first. The best frames were chosen for the left and right oculars and then reprinted on 11 X 14 inch paper for analysis.

Template Design

To analyze the 11 X 14 inch photos, a transparency overlay was created based on large target details easily processed by the combination of test NVD, the camera, and the developing and printing processes. First, the diameters of the circles dividing Zone 1 from Zone 2 and Zone 2 from Zone 3 on the data photograph under analysis were measured. A conversion factor, in MOA per inch, was then calculated by dividing the number of arc minutes the zone subtended by the zone diameter. This yielded two conversion factors per photograph, which were averaged to get a single conversion factor for the entire photograph. This factor was then used to determine the diameter of the spots on the spot template for the corresponding categories of spot sizes.

Spots of the appropriate diameters were printed using a laser printer, reduced on a photocopier, and then printed on overhead transparency film. The spots on the completed overlay transparency were then measured under a microscope to verify their size.

Figure 5 shows an example of the spot reference template. The template used pairs of spots to define the different categories into which dark spots may fall. Sets of spot pairs were grouped for use in the different zones, speeding the data reduction process by eliminating the need to hunt for the proper spot sizes of a given classification and a given zone.

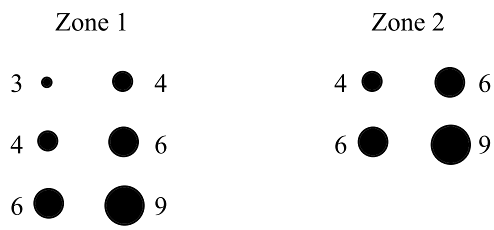

Figure 5. Spot pairs for dark spot classification.

Data and Analysis

After printing the reference spot overlay, analysis could begin. The photographic process yielded photos like Figure 6. The examination started in Zone 1 and gradually proceeded through the other zones, working clockwise. Only spots that were definitely large enough were examined further. Spots of marginal size were not counted. If a spot was considered large enough to count, its contrast was visually checked against the contrast reference photos. Spots that appeared grayer than the 30 percent contrast area on the reference photo were not counted. Spots near 30 percent but still of questionable contrast were also ignored. Only spots that were definitely large enough and dark enough to exceed the 30 percent contrast threshold were counted. Blemishes on the photos that were considered dark spots were then circled. Once the examination was completed, the examiner would have a photo with all the counted spots circled and a table of the number of spots that fell into each category in each zone.

SPOT CLASSIFICATION STUDY

Early dark spot specifications employed large classification ranges [MIL-I-49428(CR)]. This was primarily due to the belief that manufacturers could not fabricate I^2 tubes with smaller spots and that observers could not classify spot sizes with great precision. With the new set of image quality requirements [F33657-91-R-0045], allowable spots and bin sizes became smaller by about a factor of three, which raised a question about classification precision. A study was undertaken to help establish spot classification judgement criterion based on observers' visual capabilities. The results also can be applied to other spot size judgement tasks that use this range of size.

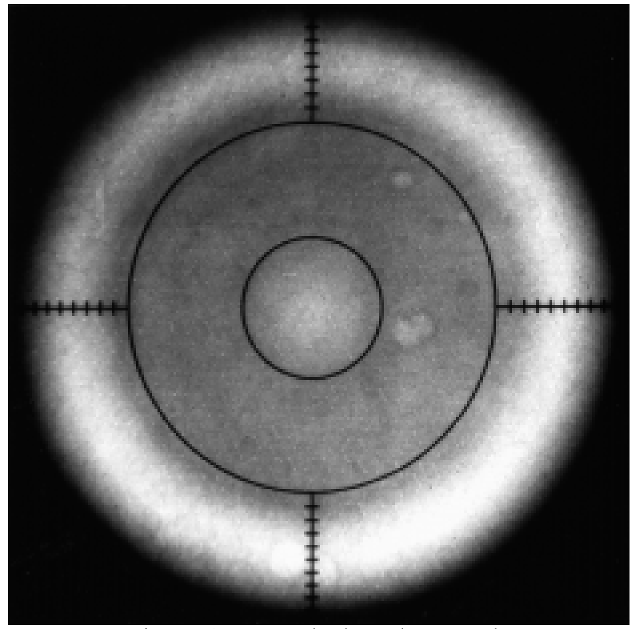

Figure 6. Example data photograph.

PROCEDURE

Ten trained observers (three women and seven men) participated in the spot classification study. All had normal distance vision correctable to 20/20 Snellen acuity without astigmatism. The observers were placed in a well-lighted room and were presented a series of high contrast targets, round, black spots on white backgrounds. Three, four, and six MOA dot sizes were used as references against which test dots were judged to be either larger or smaller. The test dots were mounted to white foam-core board to facilitate handling during the experiment. An 8 by 8 foot piece of white foam-core was used as the stimulus surround and a small ledge held the dots near the center. All targets were viewed at a distance of 100 feet. The white background was 11.6 fL and the contrast (Michelson, Equation 1) of all dots was 0.88.

Each trial consisted of the observer viewing a pair of dots; a reference standard dot and a test dot. The 48 dot pairs (a 3, 4, or 6 minute reference with one of 16 test dots), positions (reference on left or right), and repetitions (six per condition) were randomly presented in a within-subjects design. For ten observers, this yielded 2880 data points per reference dot size.

An observer was seated 100 feet from the dots. While their eyes were covered, a reference and a test dot were placed on the holder. The observer was then asked to view the pair and state which dot was smaller, then close their eyes while the next pair was set up for viewing.

RESULTS

This study showed that human evaluators could reasonably accurately classify small spots as being larger or smaller than a reference. Figures 7, 8, and 9 show the mean correct spot size classification as a function of the size difference (in tenths of a MOA) between a reference (center values 3, 4, and 6 MOA) and a test dot. Observers exhibited 100 percent accuracy in classifying test dots when the difference was at least 0.4 MOA for all spot standards tested. It should be noted that the data were asymmetrical about their respective standards. One would not expect any significant difference when comparing larger or smaller dot sizes to the standard. To further simplify analysis, the data were folded about the standard. From these combined data the ranges for 95 and 99 percent probability of correct classification were interpolated. Tables 1 & 2 show these interpolated range values for the three standards in MOA and as a percentage.

Table 1. Errors based on the 95 percent probability of a correct classification.

Reference (MOA)	**Error Bounds (± MOA)**	**Error Bounds (± Percent)**
3	0.182	6
4	0.190	5
6	0.194	3

Table 2. Errors based on the 99 percent probability of a correct classification.

Reference (MOA)	**Error Bounds (± MOA)**	**Error Bounds (± Percent)**
3	0.290	9
4	0.276	6
6	0.370	6

DISCUSSION AND CONCLUSIONS

Older dark spot test methods could not quantify the image quality of new I^2 tubes. The photographic method documented in this report achieved the required sensitivity and accuracy. Experimentation showed that human evaluation of photographic dark spot data was viable and reasonably accurate. Observers achieved a 99 percent classification accuracy for spots at least ± 9 percent different than a given standard size. For larger reference spots, error as a percentage of the reference decreased with spot size.

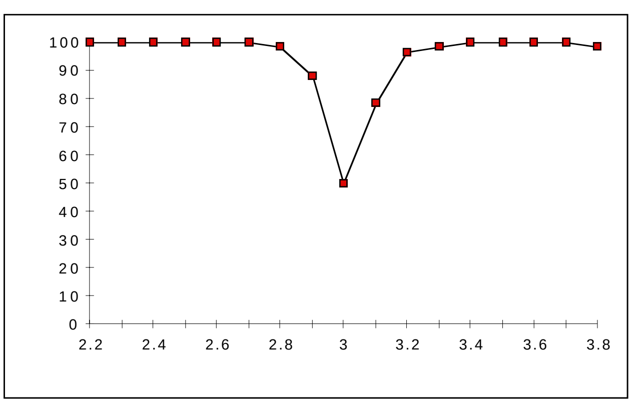

Figure 7. Mean percent correct classification for a 3 MOA reference.

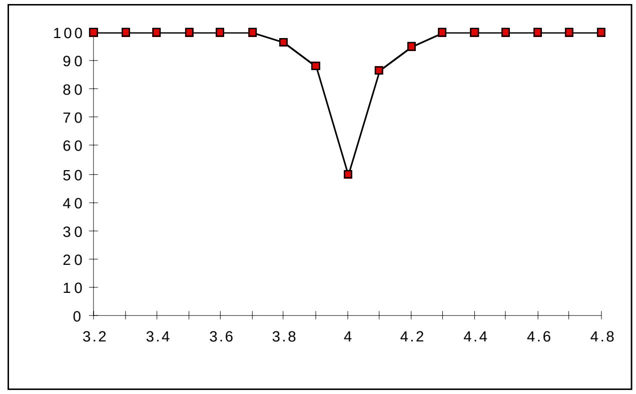

Figure 8. Mean percent correct classification for a 4 MOA reference.

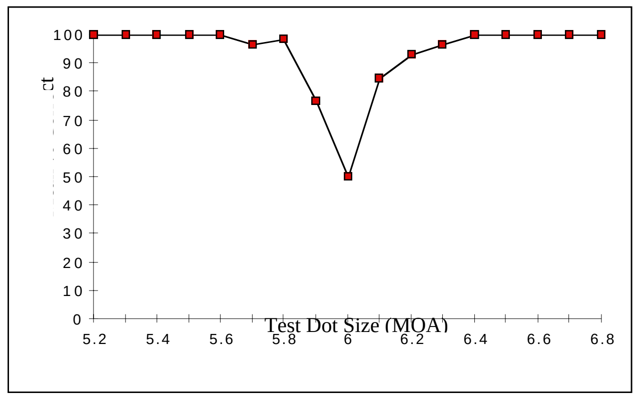

Figure 9. Mean percent correct classification for a 6 MOA reference.

This indicated several things. First, spot classification specifications could be more stringent that originally thought. Bin sizes could be made narrower due to relatively high precision in classification. Also, increasing the magnification in the printing process for Dark Spot Photos could decrease errors in photographic spot classification.

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BIOGRAPHY

Peter L. Marasco came to the U.S. Air Force in 1991 as a research physicist. His work as an optical engineer has been primarily in the areas of Night Vision and Aircraft Transparency Technology conducting basic research, guiding and executing optical and opto-mechanical design efforts, evaluating concepts and prototypes, and developing and improving optical test methods. Mr. Marasco received a BS degree from the University of Rochester in 1991 and an MS degree from the University of Arizona in 1993, both in Optical Engineering. Currently, he is working toward a Ph.D from the University of Dayton in Electro-Optical Engineering. He is a member of the SAFE Association and the Society of Photo-Optical Instrumentation Engineers (SPIE).

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(See earlier paper on NVG visual acuity.)